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RESEARCH MEMORANDUM

FLIGHT CHARACTERISTICS AT LOW SPEED OF DELTA-WING MODELS

By

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FLIGHT CHARACTERISTICS AT LOW SPEED OF DELTA-WING MODELS

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SUMMARY

An exploratory investigation to obtain a survey of the flying characteristics at low speeds of models with low-aspect-ratio delta wings has been conducted in the Langley free-flight tunnel. Four models having triangular plan-form wings with 53°, 63°, 76°, and 83° sweepback and five models having these same wings with the tips cut off to give taper ratios of 0.5 or 0.2 were used in this investigation.

It was found that the stability and control characteristics of the models with 53° or 63° sweepback and aspect ratios of 2 or 3 were fairly good. The power-off glide angles, however, were very steep at high lift coefficients. The flight characteristics of the models with 76° or 83° sweepback or aspect ratios of 1 or less were unsatisfactory because of unstable rolling oscillations at high lift coefficients or because of excessive changes in static longitudinal stability over the lift range.

INTRODUCTION

Recent research has indicated that increases in sweepback will increase the critical speed of a wing and thereby increase the speed at which compressibility effects may cause a pronounced drag rise or stability troubles. Below the speeds at which compressibility effects occur, however, the use of sweepback has introduced new stability problems in the high lift-coefficient range. It has been shown in references 1 and 2 that, in order to have satisfactory longitudinal stability at high lift coefficients with a sweptback wing, it is necessary to have low aspect ratio, but the low-aspect-ratio sweptback wings generally have high effective dihedral at high lift coefficients and are thus subject to poor Dutch roll stability. An investigation of the low-speed aerodynamic characteristics of low-aspect-ratio wings, reference 3, indicated that some delta wings (wings having roughly triangular plan form with a sweptback leading edge and straight trailing edge) might have fairly good low-speed stability characteristics. Some unpublished results on measurements of the drag of small models at supersonic speeds have indicated that the drag of delta wings might be lower than that of constant-chord sweptback wings for sweep angles less than 65°. The delta wing also seems to have some structural advantage over the constant-chord sweptback wing. In general, therefore, delta wings seem to deserve some consideration for use on high-speed airplanes.

Although the static stability characteristics of the delta wings presented in reference 3 indicated that some of the wings might have reasonably good flight behavior, the damping-in-roll derivatives were out of the normal range and some of the other stability derivatives were not known. Hence accurate estimates of the flight behavior could not be made. An investigation has been made in the Langley free-flight tunnel, therefore, to study the flying characteristics of some models with low-aspect-ratio delta wings. This investigation was of an exploratory nature and was intended only to provide a preliminary survey of the flying characteristics of delta wings over a range of sweep angles to determine whether a detail study of delta wings is justified.

Four triangular wings having a range of sweep angles between 53° and 83° were tested, and each of these wings was also tested with the wing tips cut off to give a taper ratio of 0.5. The 53° swept wing was also tested with a taper ratio of 0.2. Inasmuch as these tests were exploratory, the models were tested as simple flying wings with a vertical tail but with no horizontal tail or fuselage.

SYMBOLS

W	weight of model, pounds
S	wing area, square feet
S_t	vertical tail area, square feet
b	wing span, feet
$\bar{c}$	wing mean aerodynamic chord, feet
V	airspeed, feet per second
q	dynamic pressure, pounds per square foot $\left(\frac{1}{2}\rho V^2\right)$
A	aspect ratio $\left(\frac{b^2}{S}\right)$

Λ sweepback of leading edge, degrees

λ taper ratio $\left(\frac{\text{Tip chord}}{\text{Root chord}}\right)$

k_X radius of gyration of model about principal longitudinal axis of inertia, feet

k_Y radius of gyration of model about principal lateral axis of inertia, feet

k_Z radius of gyration of model about principal normal axis of inertia, feet

p rolling angular velocity, radians per second

ρ mass density of air, slug per cubic foot

α angle of attack, degrees

β angle of sideslip, degrees

δ_e elevon deflection, degrees, subscripts r and l denote right and left elevon deflection, respectively

τ inclination of principal longitudinal axis of inertia relative to longitudinal body axis, degrees, positive when forward end of principal axis is above longitudinal body axis

C_L lift coefficient $\left(\frac{\text{Lift}}{qS}\right)$

C_D drag coefficient $\left(\frac{\text{Drag}}{qS}\right)$

C_Y lateral-force coefficient $\left(\frac{\text{Lateral force}}{qS}\right)$

C_m pitching-moment coefficient $\left(\frac{\text{Pitching moment}}{qS\bar{c}}\right)$

C_l rolling-moment coefficient $\left(\frac{\text{Rolling moment}}{qSb}\right)$

C_n yawing-moment coefficient $\left(\frac{\text{Yawing moment}}{qSb}\right)$

$C_{L_{max}}$ maximum lift coefficient

ΔC_{l_a} change of rolling-moment coefficient produced by elevons as ailerons

ΔC_{n_a} change of yawing-moment coefficient produced by elevons as ailerons

C_{Y_β} rate of change of lateral-force coefficient with angle of sideslip in degrees $\left(\frac{\partial C_Y}{\partial \beta}\right)$

C_{l_β} rate of change of rolling-moment coefficient with angle of sideslip in degrees $\left(\frac{\partial C_l}{\partial \beta}\right)$

C_{n_β} rate of change of yawing-moment coefficient with angle of sideslip in degrees $\left(\frac{\partial C_n}{\partial \beta}\right)$

C_{l_p} rate of change of rolling-moment coefficient with rolling velocity factor in radians $\left(\frac{\partial C_l}{\partial\left(\frac{pb}{2V}\right)}\right)$

APPARATUS AND TESTS

The present investigation consisted of tests in the Langley free-flight tunnel, which is described in reference 4, to determine the stability and control characteristics of each of the nine models shown in figures 1 to 9. The models were simple flying-wing models with a vertical tail at the trailing edge of the wing but with no fuselage or horizontal tail. The airfoil used on the wings was a flat-plate type, a sketch of which is shown in figure 10. This airfoil was used because it was simple to build and because, at low scale, the aerodynamic characteristics of delta wings have been found to be virtually independent of the airfoil section. This characteristic was indicated by comparison of the delta-wing data from reference 3 with some unpublished German data on a similar series of delta wings with NACA 0012 profiles and with some unpublished data on a 60° sweptback delta wing with an NACA 0015-64 airfoil.

The control surfaces were constant-chord plain flaps at the trailing edge of the wing. These surfaces were of the type generally called elevons; that is, the two surfaces were deflected up and down together to serve as elevators and were deflected differentially to serve as ailerons.

The vertical tails used on the models varied in size but were geometrically similar having an aspect ratio of 2, taper ratio of 0.5, and no sweep of the 0.5 chord line. The vertical tail arrangements used on each of the models are illustrated in figures 1 to 9. These arrangements consisted of a single tail in the plane of symmetry on all of the models except model 2. This model was the first one tested and used a single tail in the plane of symmetry or two of these tails at the wing tips which doubled the tail area. Model 2 was the only one equipped with a movable rudder.

Inasmuch as the present investigation was of an exploratory nature and there was no precedent to indicate what mass characteristics the models should have, the models were simply ballasted to obtain either of the two center-of-gravity positions which were used during the tests. No attempt to adjust the weight or moments of inertia was made. The mass characteristics of the models, given in figures 1 to 9, were measured when the models were ballasted for the rearward of the two center-of-gravity positions which were used during the tests. This rearward center-of-gravity position is shown on the figures.

Photographs of two of the models flying in the test section of the Langley free-flight tunnel are shown as figure 11.

Each of the models was flight-tested over as wide a range of lift coefficient as possible with two center-of-gravity positions and with various vertical tail arrangements in order to determine qualitatively the stability and control characteristics and the general flight behavior. General flight behavior is the term used to describe the over-all flying characteristics of a model and indicates the ease with which the model can be flown, both for straight and level flight and for performance of the mild maneuvers possible in the Langley free-flight tunnel. Any abnormal characteristics of the model are generally judged as unsatisfactory general flight behavior, inasmuch as they are disconcerting to the free-flight-tunnel pilots. In effect, then, the general flight behavior is much the same as the pilot's opinion or "feel" of an airplane and indicates whether stability and controllability are properly proportioned.

All the flight tests were made in power-off gliding flight. The range of lift coefficient which could be covered in flight tests was limited by the maximum speed of the tunnel which determined the lowest possible lift coefficient. The highest lift coefficient was determined by the stall, by maximum glide angle of the tunnel, or by poor flying characteristics. The two center-of-gravity positions corresponded to approximately 0.05 and 0.10 static margin at moderate lift coefficients $\left(C_L \approx 0.6\right)$.

Force tests of each of the models were made to determine the static stability and control characteristics over the entire speed range. All of the forces and moments were measured with reference to the stability axes which are shown in figure 12 and to the rearward center-of-gravity positions which are shown in figures 1 to 9. The values of the stability derivatives C_{Y_β}, C_{l_β}, and C_{n_β} were determined from force tests made at angles of yaw of 5° and -5°. All the force tests were made at a dynamic pressure of 3.0 pounds per square foot which gave values of Reynolds number from 402,000 to 1,156,000 based on the mean aerodynamic chords of the wings.

Tests were made to determine the damping-in-roll parameter C_{l_p} for models 4 and 5 by the method described in reference 5. The values of C_{l_p} for the other models were available and were taken from reference 3.

RESULTS AND DISCUSSION

Interpretation of Results

The results of the force tests of some of the wings tested have been compared with some unpublished data on a delta wing having 60° sweepback which was tested in the Langley full-scale tunnel. The full-scale wing had a sharp leading edge which tended to produce the same type of flow as that encountered at low scale. Good agreement was obtained between the lift, drag, and static stability characteristics of the low-scale models and the full-scale wing with a sharp leading edge. The results of the present low-scale flight tests of delta wings, therefore, should give a fairly good indication of the flight characteristics to be expected of full-scale delta wings having sharp leading edges and similar mass characteristics. The sharp leading edge on the full-scale wing, incidentally, gave higher maximum lift values than were obtained with a round leading edge. Thus it appears that the free-flight-tunnel models simulate the more practical case.

The effects of changes in the mass characteristics on the flying characteristics of these delta-wing models were not determined. Some unpublished data from free-flight-tunnel tests of heavier delta-wing models have indicated that increases in wing loading of two times and increases in moments of inertia of about four times do not have an appreciable effect on flying characteristics.

Presentation of Results

The results of the force tests and damping-in-roll tests of the nine models are presented in figures 1 to 9 where all of the measured aerodynamic characteristics of a model are presented in the same figure. These figures are placed in the body of the paper along with the results and discussion so that the complete results (force and flight) for each model may be presented together. The results of the tests are also summarized briefly in table I in order to facilitate a comparison of the models. This type of presentation has been used because it appeared that the tests did not cover enough configurations to justify many general conclusions regarding the effects of sweep and aspect ratio on the flying characteristics of delta wings. Inasmuch as the tests were made with such simplified models, it does not appear that predictions of the flying characteristics of full-scale delta-wing airplanes are justified at the present time. No attempt has been made, therefore, to interpret the model results in terms of full-scale characteristics.

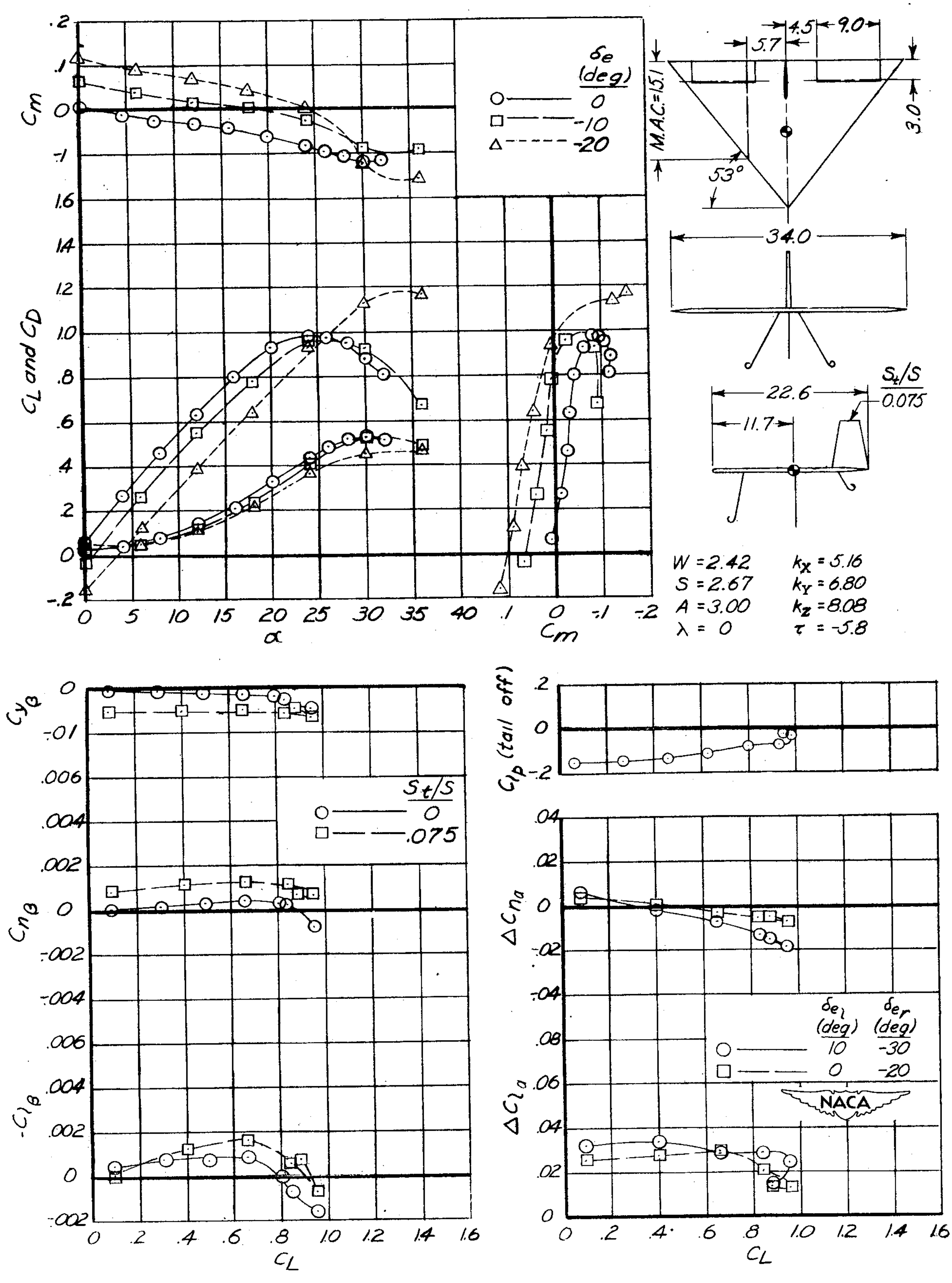

Figure 1.- Aerodynamic characteristics of model 1.

Model 1

Longitudinal stability and control.- The longitudinal stability and control characteristics of the model, with either center-of-gravity position, were fairly good over the speed range covered in the flight tests $\left(C_L = 0.20 \text{ to } 0.81\right)$. The model was not flown at the stall; however, the force tests indicated that the longitudinal stability at the stall would be satisfactory. There was, however, some difficulty in establishing trim conditions and flying the models in the free-flight tunnel. This difficulty may be due in part to unsteadiness of the flow over the wing. Smoke-flow tests on a delta wing in the Langley full-scale tunnel have shown that the air going over the wing separates from the surface at the leading edge of the wing and forms two large vortices which rotate downward at the center of the model and upward at the wing tips. This same type of flow was observed in flight tests of one of the free-flight-tunnel models with streamers of string attached to the upper surface of the wing.

The principal cause of the difficulty in flying this model, however, was apparently the large variation of drag with lift which is generally a characteristic of low-aspect-ratio swept wings and is shown by the force-test results. This large variation of drag with lift caused large variations of glide angle with lift coefficient since the trim glide angle is a function of the drag-lift ratio. The minimum glide angle occurred at a fairly low lift coefficient $\left(C_L \approx 0.3\right)$ for the model instead of near the stall as with conventional models. The response of the model to the elevator control was normal when the model was trimmed to fly at lift coefficients below that corresponding to the minimum glide angle. That is, deflecting the elevator downward increased the glide angle and deflecting the elevator upward decreased the glide angle. When the model was trimmed to fly at lift coefficients above that corresponding to the minimum glide angle, however, the response of the model to the elevator was not normal. Deflecting the elevator downward caused the glide angle to become steeper for a short time until the speed of the model increased and approached the new trim speed. The glide angle then became flatter as the model approached the new trim condition. The opposite dynamic behavior followed an upward elevator deflection; that is, the glide angle at first was flatter and then became steeper as the new trim condition was approached.

Lateral stability and control.- The lateral stability and control characteristics of the model were good over the speed range covered in the flight tests. The force tests indicate that the effective dihedral as measured by the parameter $-C_{l_\beta}$ was slightly negative at the stall. The model was not flown at the stall but experience with conventional models (reference 6) has indicated that a small amount of negative effective dihedral is not particularly objectionable.

General flight behavior.- The general flight behavior of the model was fairly good. The only difficulty which was encountered was caused by the unusual effect of elevator control on glide angle which previously has been described. At times this characteristic was very troublesome to the pilot because of the difficulty it caused in determining which direction to move the elevator to cause the model to move up or down within the tunnel. A brief deflection of the elevator caused one effect whereas holding that deflection caused the opposite effect. The significance of this response to the elevator for the pilot of the full-scale airplane has not been definitely determined, but NACA pilots believed that this behavior would be objectionable.

With no vertical tail, the model could be flown at high lift coefficients although the general flight behavior was poor because of insufficient directional stability. At low lift coefficients without a vertical tail, however, the directional stability was so low that no flights were possible.

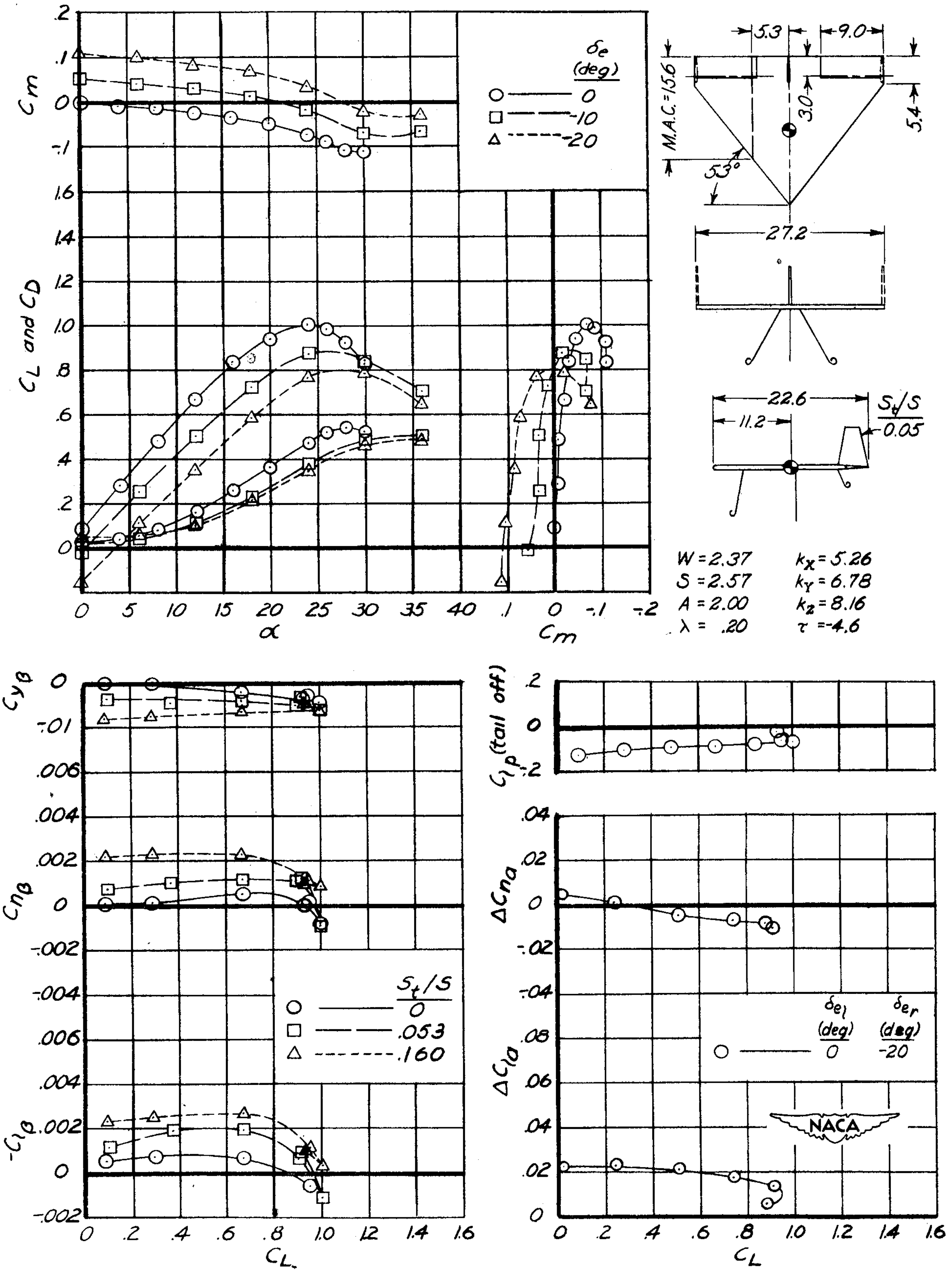

Figure 2.- Aerodynamic characteristics of model 2.

Model 2

Longitudinal stability and control.– The longitudinal stability and control characteristics of the model, with either center-of-gravity position, were fairly good over the entire speed range $(C_L = 0.15 \text{ to } 0.84)$. The same objectionable variation of glide angle with lift coefficient was encountered, however, as was encountered with model 1. These characteristics are discussed in detail for model 1.

When the center of gravity was in the rearward position, a maximum lift coefficient of 0.84 was obtained with -9° elevon deflection. Increasing the upward elevon deflection above -9° resulted in a decrease in lift coefficient until the stall was reached with -32° elevon deflection. This unusual behavior is indicated by the pitching-moment curves from the force tests and is a characteristic of the tailless configuration which was tested. The longitudinal stability of the model at the stall was considered satisfactory.

Lateral stability and control.– The lateral stability of the model, with either vertical tail arrangement, was good over the entire speed range and apparently increased with increasing lift coefficient. The directional instability at the stall shown by the force tests for the configuration with the small tail was not encountered in the flight tests. Apparently deflecting the elevons upward for longitudinal trim caused an increase in the directional stability at the stall.

The lateral control characteristics of the model were good over the speed range between lift coefficients of 0.15 and 0.84 when the elevons alone were used for control. As the elevon angle was increased above that required for maximum lift, however, the effectiveness of the elevons in controlling the model was reduced until at the stall the elevons were virtually ineffective. When the rudder was used as the sole lateral control, the model could be flown at low and moderate lift coefficients but could not be flown at high lift coefficients because there was insufficient dihedral effect to roll the model. The force tests show this drop in effective dihedral at high lift coefficients.

The flying characteristics of this model indicated that it was unnecessary to use the rudder when the elevons were used to roll the delta-wing model because there was no apparent adverse yawing in a roll with the elevons alone. This characteristic may be attributed to the favorable yawing moment due to elevon deflection at low lift coefficients shown by the force tests and to favorable yawing moments due to rolling at high lift coefficients. It is shown in reference 7 that highly swept wings have favorable yawing moments due to rolling at moderate and high lift coefficients.

General flight behavior.– The general flight behavior of the model was fairly good with either center-of-gravity position or vertical tail arrangement. The unusual variation of glide angle with lift coefficient caused the same difficulty that was experienced with model 1.

The reduction in the rolling effectiveness of the elevons with increasing angles of attack above that required for maximum lift was partially compensated by the increase in lateral stability, so that the model could be flown steadily although it was not very maneuverable. The model could not be flown at the stall, however, because the elevons were virtually ineffective for rolling the model so that the mild roll off at the stall could not be controlled.

With no vertical tail the model could be flown satisfactorily at high lifts, but at low lift coefficients the general flight behavior was unsatisfactory for the tail-off configuration because of insufficient directional stability.

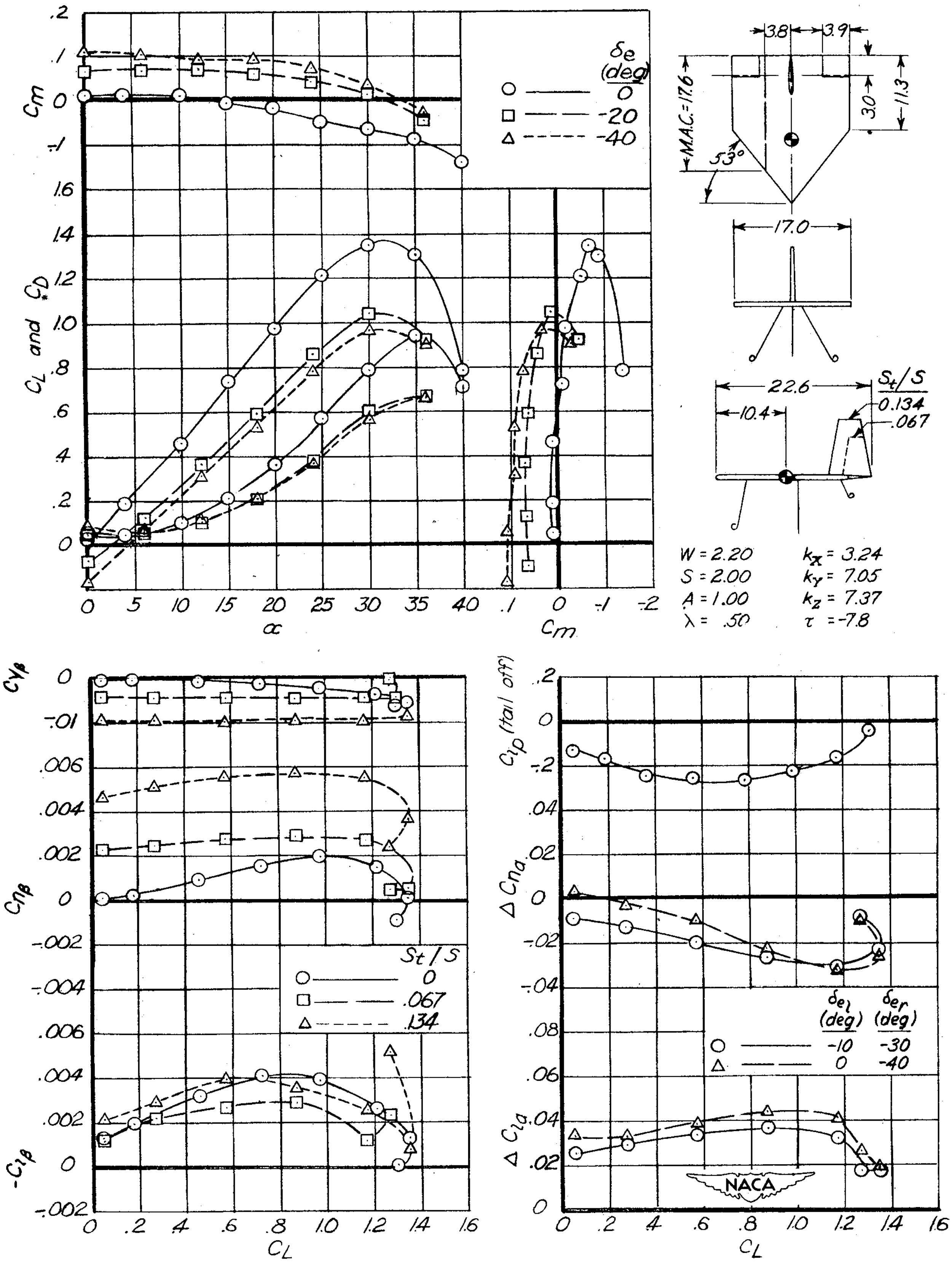

Figure 3.- Aerodynamic characteristics of model 3.

Model 3

Longitudinal stability and control.- The longitudinal stability and control characteristics of the model were unsatisfactory because of an excessive variation of static longitudinal stability with lift coefficient. This variation is indicated by the pitching-moment data from the force tests which show a change in static margin dC_m/dC_L of about 0.2 over the range of lift coefficient. When the center of gravity of the model was in the rearward position the longitudinal stability was unsatisfactory at low lift coefficients because of low static longitudinal stability. The static longitudinal stability increased with increasing lift coefficient, however, and the longitudinal stability was satisfactory at moderate and high lift coefficients. When the center of gravity was in the forward position the model had sufficient static longitudinal stability at low lift coefficients, but because of the increase in static stability with increasing lift coefficient, the elevons could not trim out the large pitching moments at high lift coefficients and could not trim the model to lift coefficients above a value of about 0.75.

In addition to these longitudinal stability and control troubles the variation of glide angle with lift coefficient caused the same difficulties as were encountered with model 1. These difficulties are discussed in detail for model 1.

The model was not flown at the stall, but the force-test data indicate that it was statically stable at the stall.

Lateral stability and control.- The model, with either vertical tail, had good lateral stability over the speed range covered in the flight tests $\left(C_L = 0.21 \text{ to } 0.83\right)$, and the stability of the lateral oscillations appeared to increase with increasing lift coefficient.

The lateral control characteristics were good at lift coefficients below a value of 0.70. At higher lift coefficients, however, the response of the model to the controls was weak. This weakness might be attributed partly to the large adverse yawing moments (fig. 3) caused by the short-span, wide-chord elevons used on this model. The adverse yawing due to elevons and the high effective dihedral of this model evidently caused large rolling moments which opposed the elevon rolling moments at high lift coefficients and thus reduced the rolling effectiveness of the elevons.

General flight behavior.- The general flight behavior of the model was unsatisfactory because of the excessive variation of static longitudinal stability with lift coefficient. This variation caused the model to have unsatisfactory longitudinal stability at low lift coefficients when the center of gravity was in the rearward position or caused the elevons to be inadequate for trimming to high lift coefficients when the center of gravity was in the forward position. Although some intermediate center of gravity might give satisfactory flight behavior over the entire speed range, this plan form does not seem to be practical for tailless airplanes because of the limited allowable center-of-gravity movement.

The lateral flight behavior was good at lift coefficients below 0.70 but was only fair at higher lift coefficients because of the decrease in the effectiveness of the lateral controls.

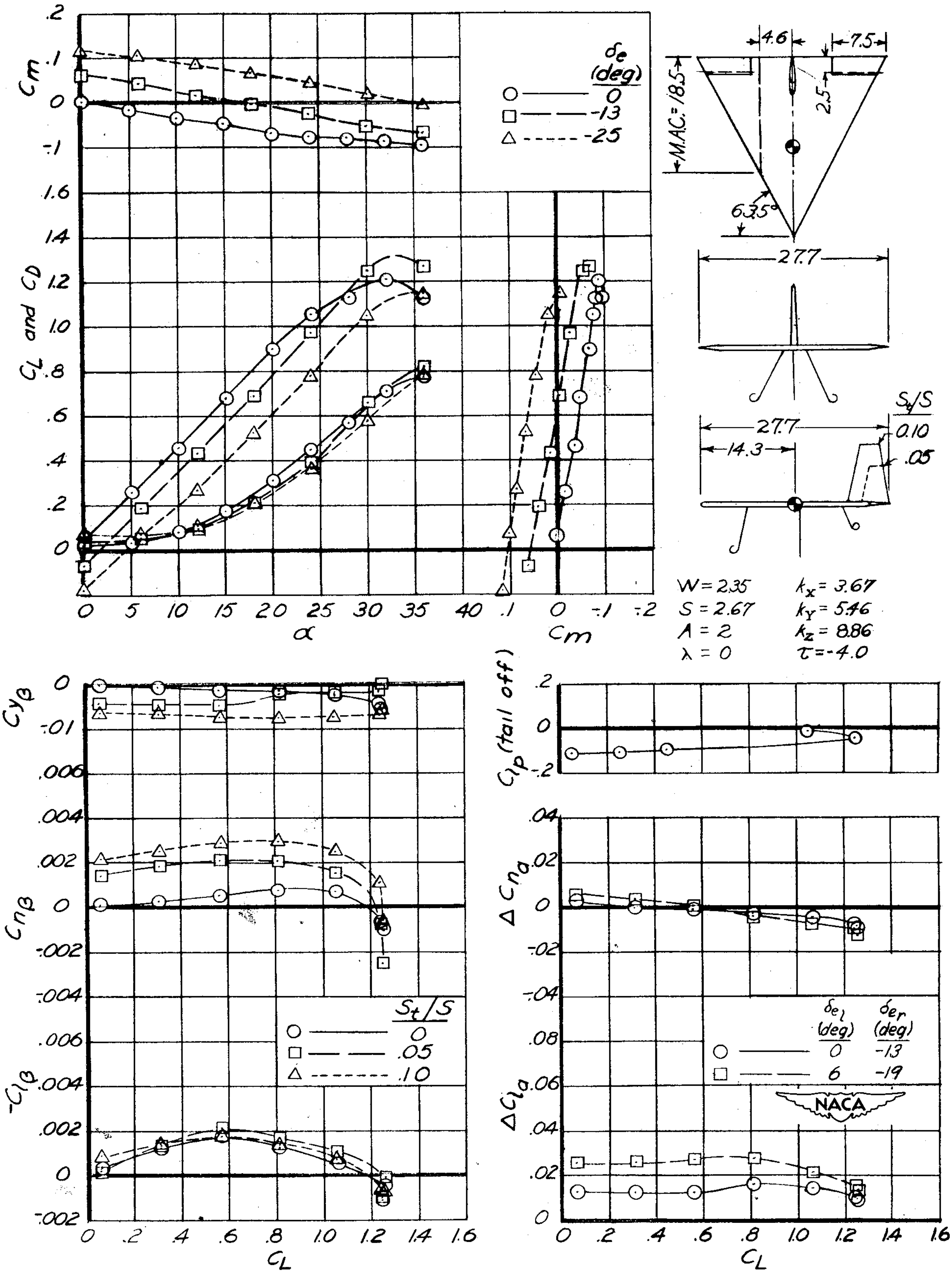

Figure 4.- Aerodynamic characteristics of model 4.

Model 4

Longitudinal stability and control.- The longitudinal stability and control characteristics of the model, with either center-of-gravity position, were found to be fairly good over the entire speed range $(C_L = 0.10 \text{ to } 1.06)$. The only undesirable longitudinal characteristic was the unusual response of the model glide angle to elevator deflection. This characteristic has been discussed in detail for model 1 which had the same type of behavior. Model 4 was flown at the stall, and its longitudinal stability and control characteristics in this condition were considered fairly satisfactory inasmuch as the model was stable and recoveries could generally be made from the stalled condition by means of the elevons.

Lateral stability and control.- The lateral stability of the model, with either vertical tail, was fairly good over the entire speed range. Although there was a noticeable reduction in stability with increasing lift coefficient, the lateral stability appeared to be satisfactory for the controls-fixed case. At times, however, when there was play in the elevon control system, a small-amplitude, steady rolling oscillation was evident at lift coefficients above a value of about 0.70.

The lateral control characteristics of the model were good at lift coefficients below a value of 0.75. At higher lift coefficients, however, there was noticeable decrease in the effectiveness of the controls as the lift coefficient was increased. At the stall the effectiveness of the elevons for rolling the model was too low to be satisfactory.

General flight behavior.- The general flight behavior of the model was fairly good. In spite of the fact that the lateral stability and control effectiveness decreased with increasing lift coefficient, the model was easy to fly at high lift coefficients. It was quite steady at high lift coefficients although it was not as maneuverable as might have been desired. There were two objectionable points about the flight behavior, however, which should be pointed out. The unusual response of the model glide angle to elevator deflection caused some difficulty, and the low rolling effectiveness of the elevons at the stall was definitely objectionable because the model could not always be controlled in a stall although the roll-off was very slow.

The general flight behavior of the model was poor when it was flown without a vertical tail because of high dihedral effect and low directional stability. This combination of factors caused excessive yawing so that the rolling moments due to sideslip often overpowered those due to the elevons.

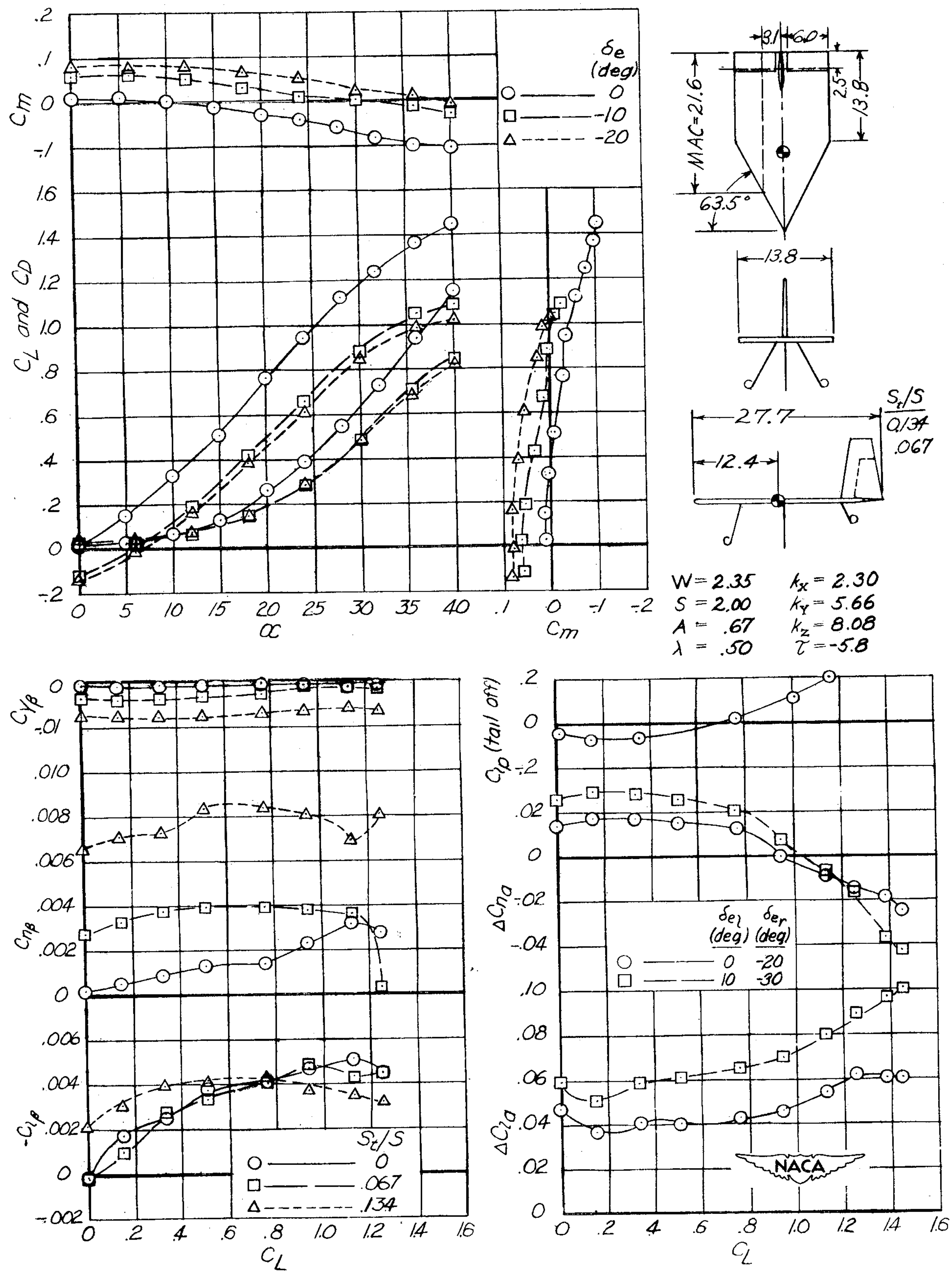

Figure 5.- Aerodynamic characteristics of model 5.

Model 5

Longitudinal stability and control.– The longitudinal stability and control characteristics of the model were unsatisfactory because of excessive changes in static stability. This same difficulty was encountered with model 3 and is discussed in detail for that model. In addition to this longitudinal stability and control trouble, the unusual variation of glide angle with lift coefficient caused the same difficulties as were encountered with model 1. These difficulties are discussed in detail for model 1. Model 5 was not flown at the stall, but the force–test data indicated that the static longitudinal stability at the stall was satisfactory.

Lateral stability and control.– The model, with either vertical tail, had good lateral stability at lift coefficients below 0.75, but a constant–amplitude lateral oscillation was evident at lift coefficients above 0.75. The amplitude of this oscillation appeared to increase with increasing lift coefficient to an amplitude of about $\pm 10^{\circ}$ bank at a lift coefficient of 1.00. These lateral oscillations appeared to be almost pure rolling oscillations with no evident yawing. The motion, however, was probably the familiar Dutch–roll oscillation with the rolling predominating in this case because of the relatively large values of effective dihedral and small values of rolling moments of inertia and the damping–in–roll parameter C_{l_p}. This combination of factors tends to cause large rolling motions, and the relatively large values of yawing moments of inertia and directional stability tend to suppress the yawing motion. The lift coefficient at which the rolling oscillation became unstable was approximately the same as the lift coefficient at which the damping in roll C_{l_p} became unstable (see fig. 5). Thus it appears that the constant–amplitude rolling oscillations and subsequent rolling instability were caused primarily by small or unstable values of damping in roll.

The lateral control characteristics of the model were good over the speed range covered in the flight tests $\left(C_L = 0.21 \text{ to } 1.00\right)$. There was, however, a noticeable reduction in the rolling effectiveness of the elevons with increasing lift coefficient above a value of 0.75. This reduction in elevon effectiveness was evidently caused by the adverse yawing moments due to elevon deflection (shown in fig. 5) which caused appreciable rolling moments due to sideslip to oppose the elevon rolling moments.

General flight behavior.– The general flight behavior of the model was unsatisfactory for several reasons. The variation of static longitudinal stability with lift coefficient caused the model to have unsatisfactory longitudinal stability at low lift coefficients when the center of gravity was in the rearward position, or caused large pitching moments at high lift coefficients which could not be trimmed out by the elevons when the center of gravity was in the forward position. The unusual response of the model glide angle to elevator deflection was objectionable. The constant–amplitude rolling oscillation at lift coefficients above a value of 0.75 was definitely objectionable. The model responded to the controls, however, and could be flown within the confines of the tunnel in spite of the fact that the pilot could not stop the rolling oscillation. The constant–amplitude, high–frequency rolling oscillation was superimposed on the motions due to the controls.

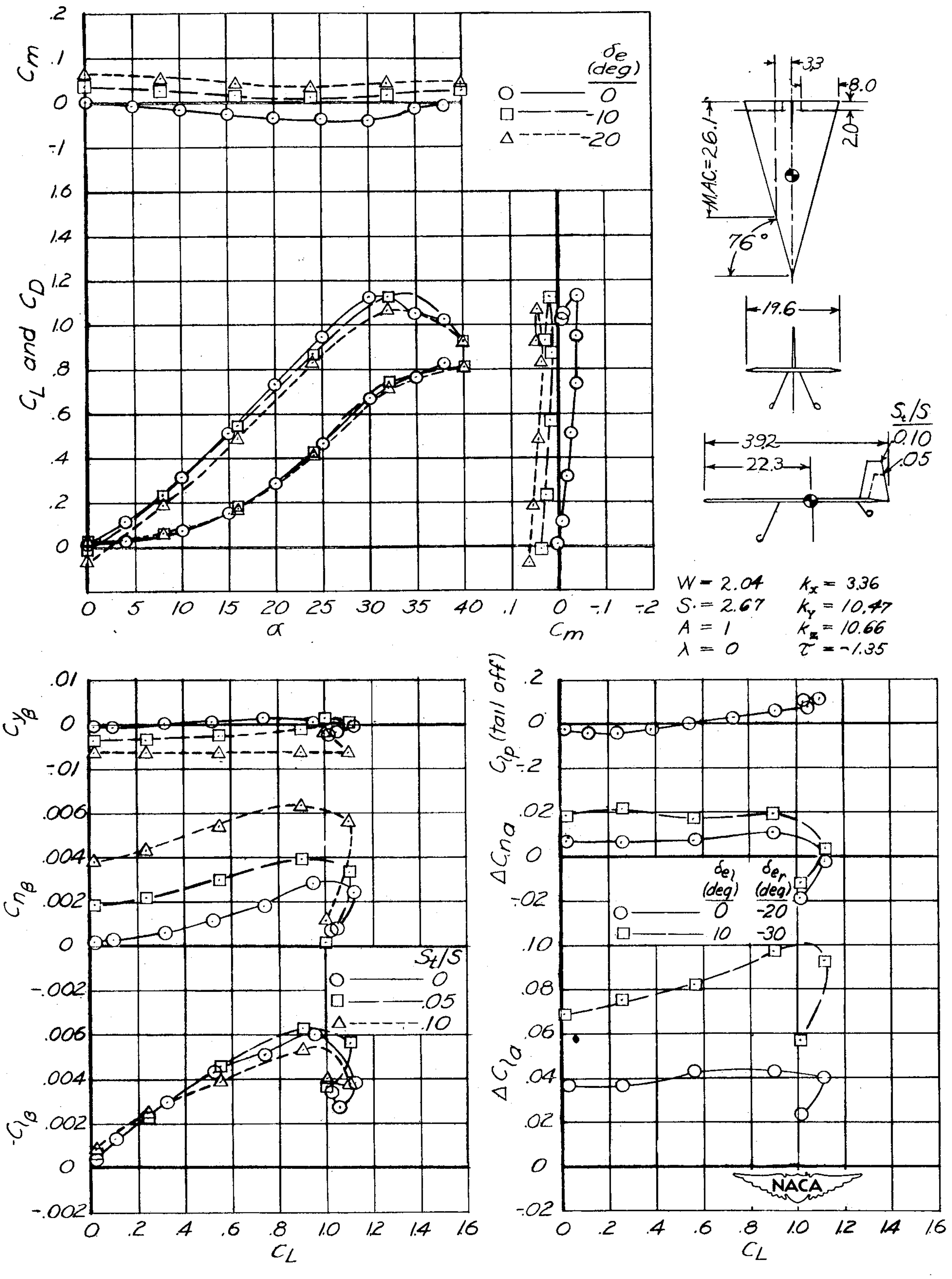

Figure 6.- Aerodynamic characteristics of model 6.

Model 6

Longitudinal stability and control.- The longitudinal stability and control characteristics of the model, with either center-of-gravity position, were fairly good over the speed range covered in the flight tests $\left(C_L = 0.23 \text{ to } 0.50\right)$. The same difficulties in establishing trim conditions and flying the model were encountered as were encountered with model 1. The model was not flown at the stall, but the force-test data show static longitudinal instability at the stall.

Lateral stability and control.- The model had fair lateral stability at lift coefficients below 0.32 with either vertical tail. A constant-amplitude rolling oscillation similar to that obtained with model 5 was encountered at lift coefficients between 0.32 and 0.50. At lift coefficients above 0.50 the rolling oscillations were unstable and increased in amplitude until the model rolled completely over.

The lateral control characteristics of the model were good over the speed range covered in the flight tests.

General flight behavior.- The general flight behavior of the model was fair at lift coefficients below 0.32 with either vertical tail. At higher lift coefficients the general flight behavior was poor. The model could not be flown at lift coefficients above 0.50 because of the unstable rolling oscillation which caused the model to roll completely over out of control. The model could not be flown without a vertical tail in spite of the fact that the force tests showed a fair amount of directional stability. The effective dihedral was high in proportion to the directional stability and the damping in roll was low. Because of this combination of factors, the model would roll off rapidly when it yawed, and the rolling moment due to the sideslip generally overpowered that due to the elevons so that the model could not be controlled.

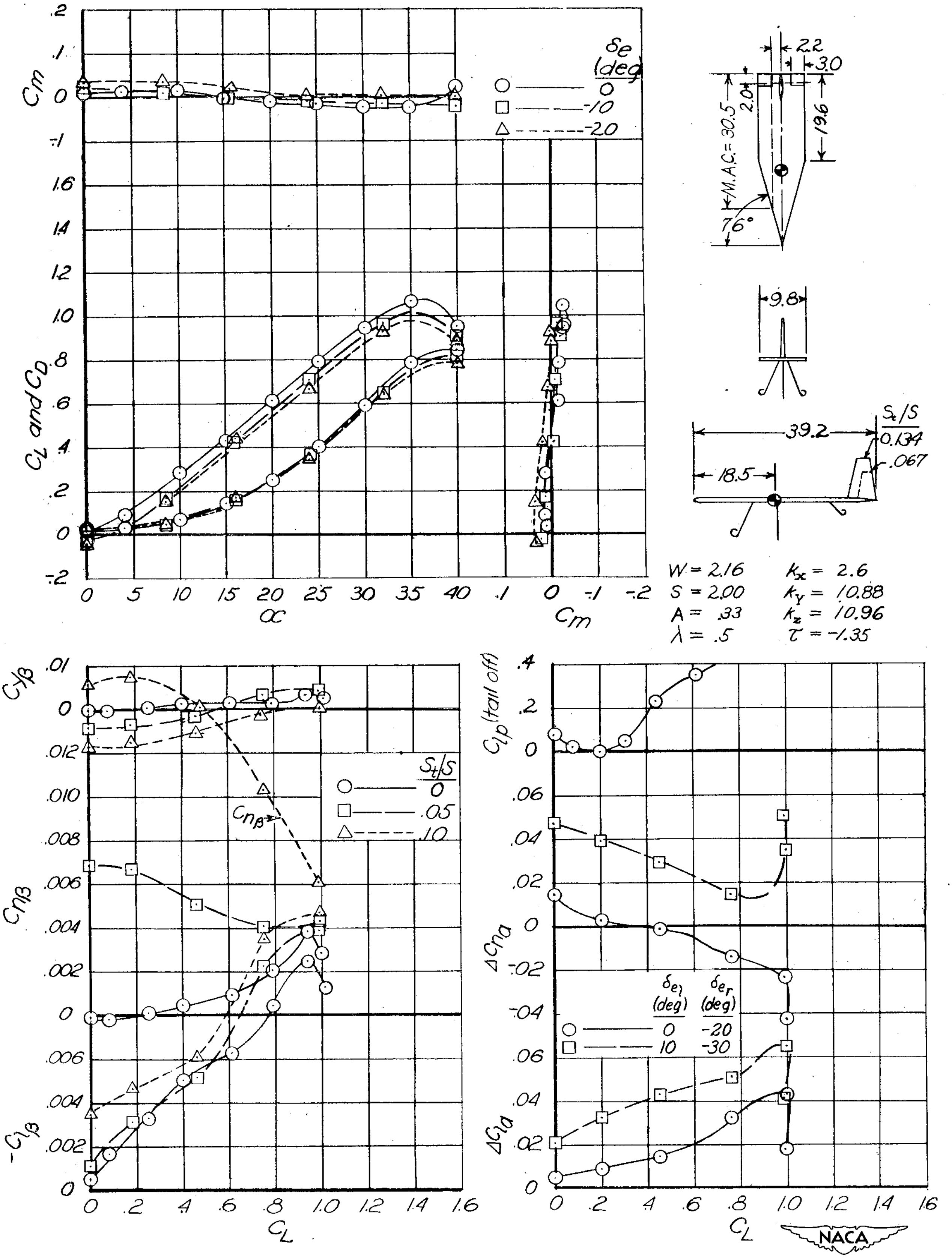

Figure 7.- Aerodynamic characteristics of model 7.

Model 7

<u>Longitudinal stability and control</u>.— The longitudinal stability and control characteristics of the model, with either center-of-gravity position, were good over the speed range covered in the flight tests $\left(C_L = 0.12 \text{ to } 0.28\right)$. This model was not flown at the stall, but the force-test data indicate static longitudinal instability at the stall.

<u>Lateral stability and control</u>.— The model had fair lateral stability at lift coefficients below 0.18 with either vertical tail. A constant-amplitude rolling oscillation similar to that described on model 5 was encountered at lift coefficients between 0.18 and 0.28. At lift coefficients above 0.28 the rolling oscillations were unstable as on model 6.

The lateral control characteristics were good at lift coefficients below 0.24. At higher lift coefficients the lateral control became weak.

<u>General flight behavior</u>.— The general flight behavior of the model was fair at lift coefficient below 0.18 with either vertical tail. At higher lift coefficients the general flight behavior was poor. The model could not be flown at lift coefficients above 0.28 because of the unstable rolling oscillation. The model could not be flown without a vertical tail because of insufficient directional stability.

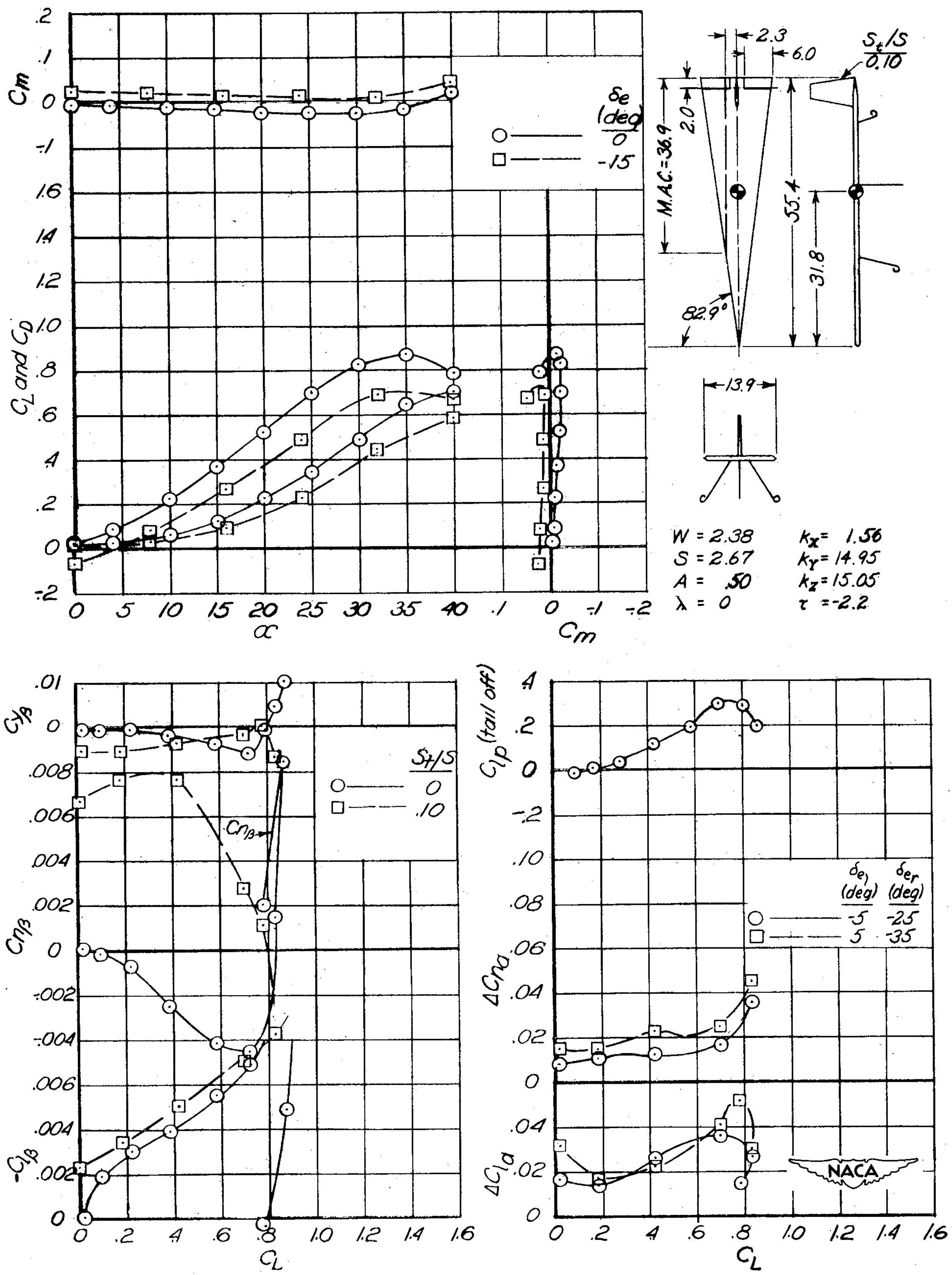

Figure 5.- Aerodynamic characteristics of model 5.

Model 8

Longitudinal stability and control.— The longitudinal stability and control characteristics of the model, with either center-of-gravity position, were good over the speed range covered in the flight tests $\left(C_L = 0.07 \text{ to } 0.28\right)$. This model was not flown at the stall, but the force-test data indicate static longitudinal instability at the stall.

Lateral stability and control.— The model had fair lateral stability at lift coefficients below 0.18. A constant-amplitude rolling oscillation similar to that of model 5 was encountered at higher lift coefficients between 0.18 and 0.28. At lift coefficients above 0.28 the rolling oscillations were unstable as on model 6.

The lateral control characteristics were good at lift coefficients below 0.24. At higher lift coefficients the lateral control became weak.

General flight behavior.— The general flight behavior of the model was fair at lift coefficients below 0.18. At higher lift coefficients the general flight behavior was poor. The model could not be flown at lift coefficients above 0.28 because the rolling oscillation was unstable.

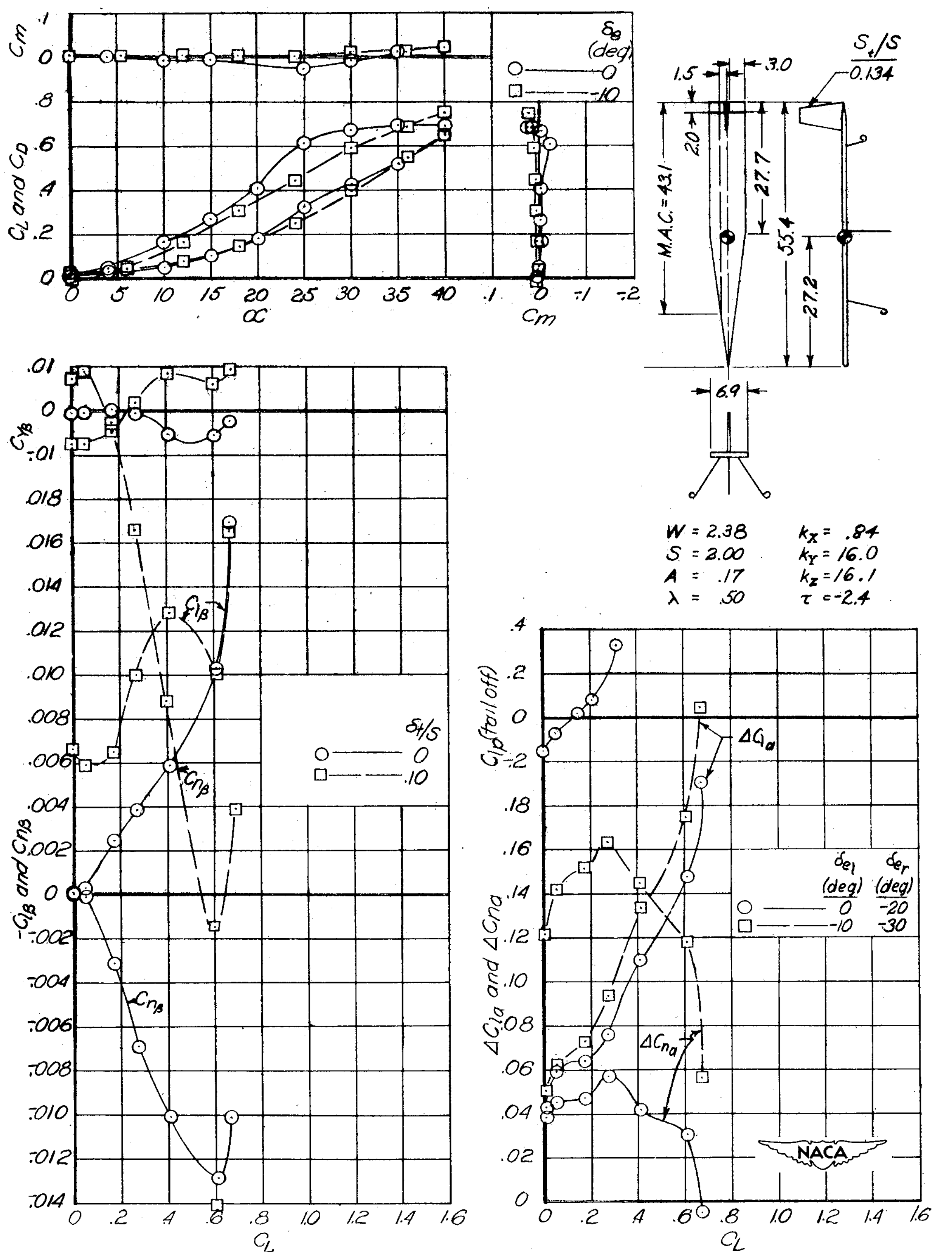

Figure 9.- Aerodynamic characteristics of model 9.

Model 9

Longitudinal stability and control.– The longitudinal stability and control characteristics of the model, with either center-of-gravity position, were good over the speed range covered in the flight tests $\left(C_L = 0.12 \text{ to } 0.20\right)$. This model was not flown at the stall, but the force-test data indicate static longitudinal instability at the stall.

Lateral stability and control.– The model was laterally stable at lift coefficients below 0.17. A constant-amplitude rolling oscillation similar to that obtained with model 5 was encountered at lift coefficients between 0.17 and 0.20. At lift coefficients above 0.20 the rolling oscillations were unstable as on model 6.

The lateral control characteristics were good over the speed range covered in the flight tests.

General flight behavior.– The general flight behavior of the model was poor at lift coefficients below 0.20. The model rolled so rapidly as a result of external disturbances that it was almost unflyable. At lift coefficients above a value of 0.20 the model became unflyable because of the unstable high-frequency rolling oscillation.

SUMMARY OF RESULTS

Models 1, 2, and 4 had very similar flying characteristics. Models 1 and 2 had 53° sweepback and aspect ratios of 3 and 2, respectively, whereas model 4 had 63° sweepback and an aspect ratio of 2. The general flight behavior of these models was fairly good and compared favorably with that of good conventional models except for an unusual response of the model glide angle to elevator deflection. This characteristic, which is described in detail for model 1, was objectionable to the free-flight-tunnel pilot although the models could be flown fairly easily once the trim conditions of airspeed and glide angle were established. NACA airplane test pilots have expressed an opinion that this unusual response to the elevator control would be objectionable to the pilot of a full-scale airplane.

The power-off glide angles of these models was very steep (about 30° at the stall) at high lift coefficients because of the sweepback and low aspect ratio of the models. These steep power-off glide angles, and consequent high sinking speeds, would probably constitute a major hazard.

Models 3 and 5, which had 53° and 63° sweepback and aspect ratios of 1 and 2/3, respectively, had similar unsatisfactory longitudinal stability and control characteristics which were caused by an excessive change in static longitudinal stability over the speed range.

Models 5 to 9 had unsatisfactory flight behavior because of high-frequency, constant-amplitude, or unstable rolling oscillations at high lift coefficients. In addition to the poor lateral stability characteristics, models 6 to 9, which had sweepback angles of 76° and 83° and aspect ratios between 1 and 1/6, had static longitudinal instability at the stall.

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National Advisory Committee for Aeronautics
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5. Bennett, Charles V., and Johnson, Joseph L.: Experimental Determination of the Damping in Roll and Aileron Rolling Effectiveness of Three Wings Having 2°, 42°, and 62° Sweepback. NACA TN No. 1278, 1947.

6. McKinney, Marion O., Jr.: Experimental Determination of the Effects of Dihedral, Vertical-Tail Area, and Lift Coefficient on Lateral Stability and Control Characteristics. NACA TN No. 1094, 1946.

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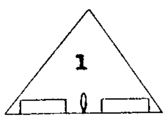
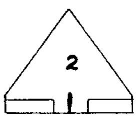
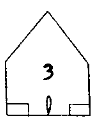
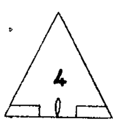
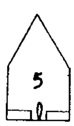
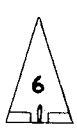
TABLE I.- SUMMARY OF STABILITY AND CONTROL CHARACTERISTICS OF THE MODELS

Plan form		Range of C_L flown	$C_{L_{max}}$ $\delta = 0^{\circ}$	Longitudinal characteristics	Lateral characteristics
	$\Lambda = 53^{\circ}$ $A = 3.00$ $\lambda = 0$	0.20 to 0.81	0.97	Good at speeds covered in flight tests. Force tests indicate stability at the stall	Good at speeds covered in flight tests. Force tests indicate good behavior up to the stall
	$\Lambda = 53^{\circ}$ $A = 2.00$ $\lambda = 0.2$	0.15 to 0.84	1.00	Good over entire speed range	Good over entire speed range
	$\Lambda = 53^{\circ}$ $A = 1.00$ $\lambda = 0.5$	0.21 to 0.83	1.35	Unsatisfactory because of large change in static stability over the speed range	Stability characteristics good at speeds covered in flight tests. Control weak at lift coefficients above 0.70
	$\Lambda = 63^{\circ}$ $A = 2.00$ $\lambda = 0$	0.10 to 1.06	1.27	Good over entire speed range	Good over entire speed range
	$\Lambda = 63^{\circ}$ $A = 0.67$ $\lambda = 0.5$	0.21 to 1.00	1.45	Unsatisfactory because of large change in static stability over the speed range	Good at lift coefficients below 0.75. Steady rolling oscillation at lower speeds. Control weak at lift coefficients above 0.75.
	$\Lambda = 76^{\circ}$ $A = 1.00$ $\lambda = 0$	0.23 to 0.50	1.13	Good at speeds covered in flight tests. Force tests show instability at the stall	Fair at lift coefficients below 0.32. Steady rolling oscillation at lower speeds. Unflyable at lift coefficients above 0.50
	$\Lambda = 76^{\circ}$ $A = 0.33$ $\lambda = 0.5$	0.12 to 0.28	1.00	Good at speeds covered in flight tests. Force tests show instability at the stall	Fair at lift coefficients below 0.18. Steady rolling oscillation at lower speeds. Unflyable at lift coefficients above 0.28
	$\Lambda = 83^{\circ}$ $A = 0.50$ $\lambda = 0$	0.07 to 0.28	0.88	Good at speeds covered in flight tests. Force tests show instability at the stall	Fair at lift coefficients below 0.18. Steady rolling oscillation at lower speeds. Unflyable at lift coefficients above 0.28
	$\Lambda = 83^{\circ}$ $A = 0.17$ $\lambda = 0.5$	0.12 to 0.20	0.69	Good at speeds covered in flight tests. Force tests show instability at the stall	Poor at lift coefficients below 0.17. Unflyable at lift coefficients above 0.20

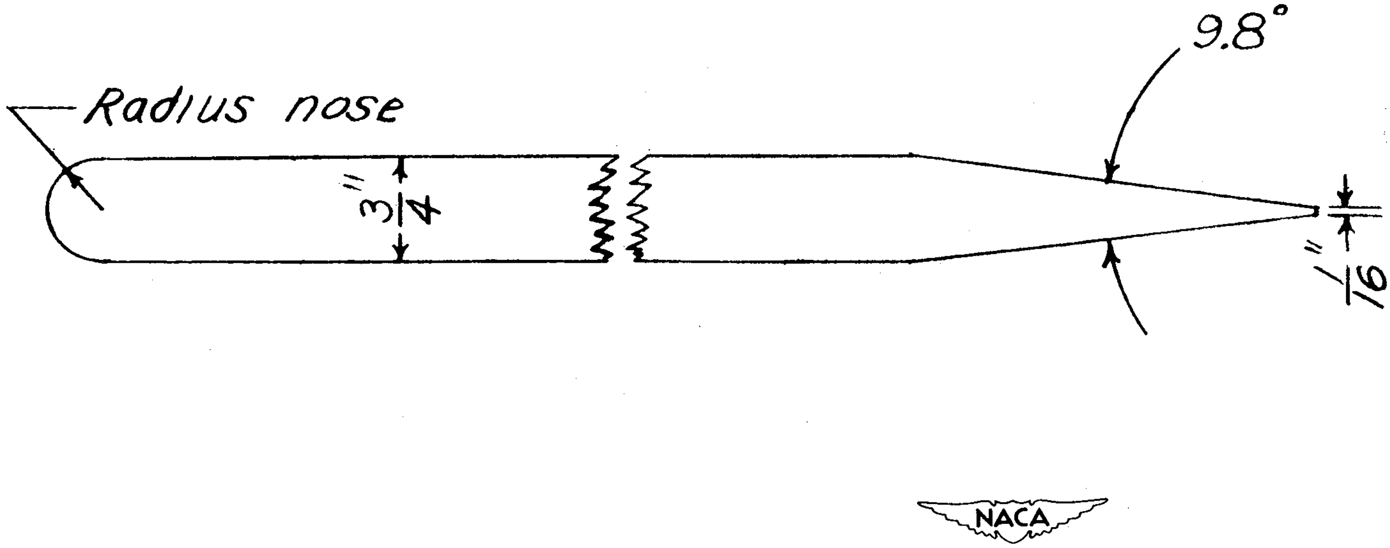
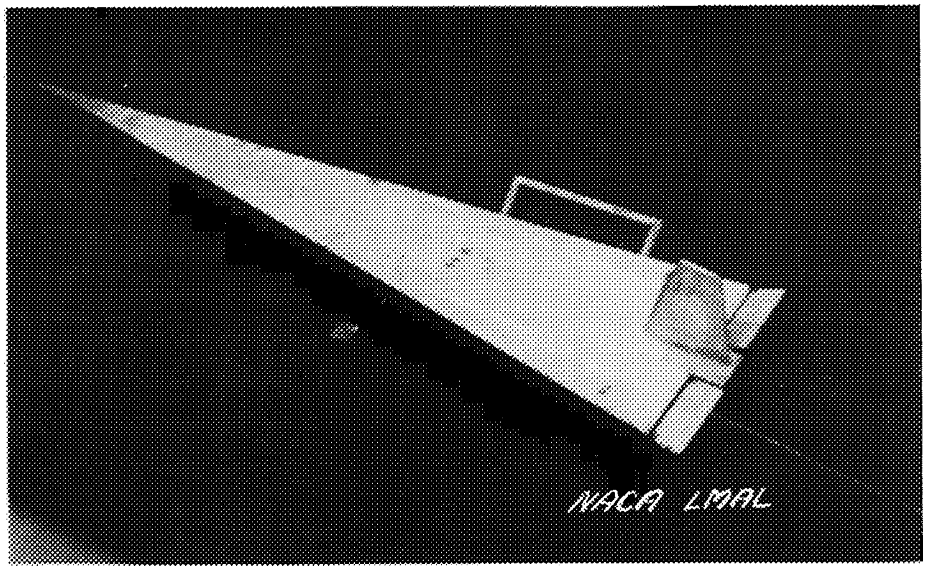
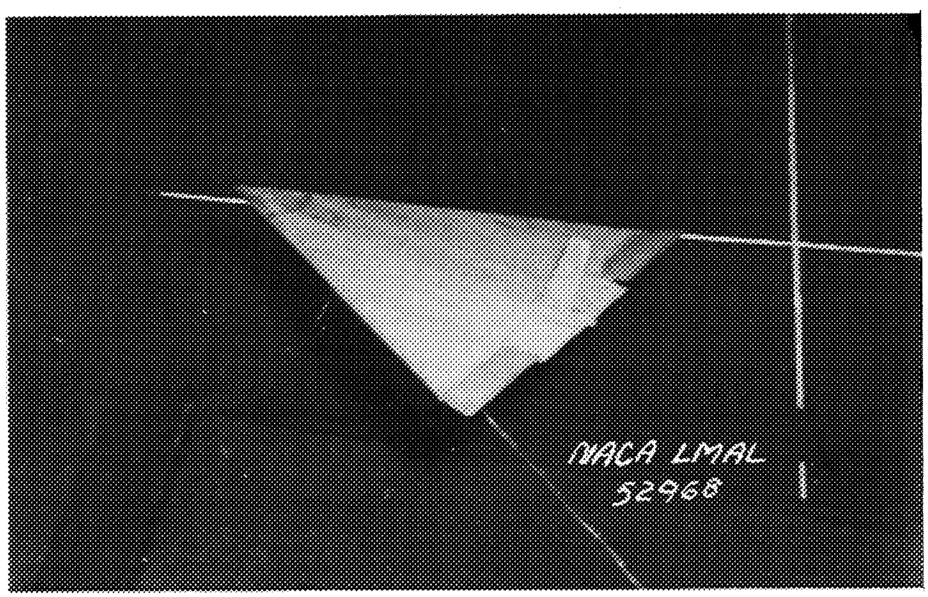


Figure 10.— Airfoil section used on models.



(a) Model 8.



(b) Model 4.

Figure 11.- Delta-wing models flying in the Langley free-flight tunnel.

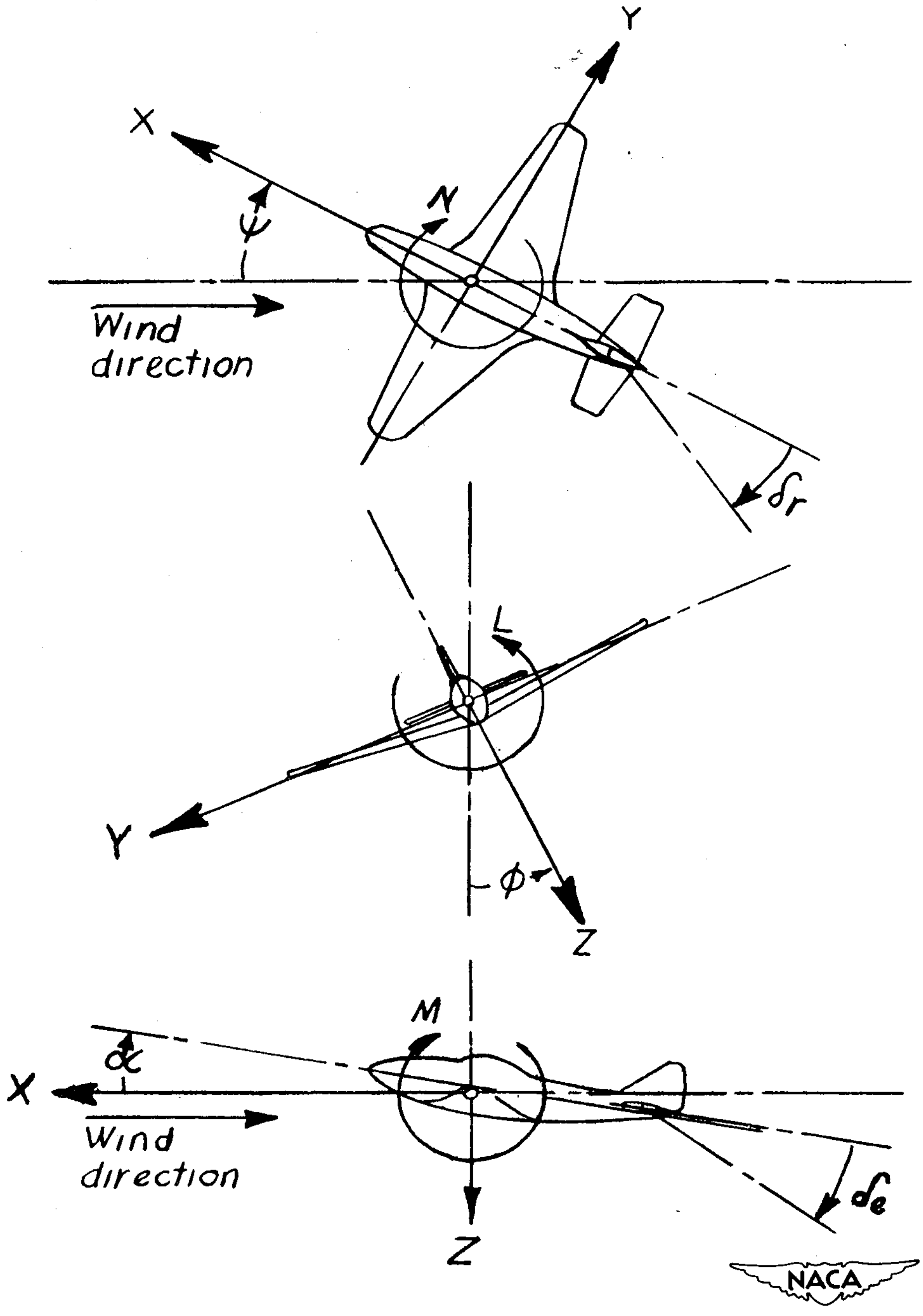


Figure 12.- The stability system of axes. Arrows indicate positive directions of moments, forces, and control-surface deflections. This system of axes is defined as an orthogonal system having their origin at the center of gravity and in which the Z-axis is in the plane of symmetry and perpendicular to the relative wind, the X-axis is in the plane of symmetry and perpendicular to the Z-axis, and the Y-axis is perpendicular to the plane of symmetry.